Toughening wood/polypropylene composites with polyethylene octene elastomer (POE)

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Abstract: Polyethylene octene elastomer (POE) as impact modifier was incorporated into wood/polypropylene composites (WPC) to enhance the impact strength of the composite. Two extruding routes, i.e. direct extruding route and two-stage extruding route, were adopted to produce Wood Powder/PP/POE ternary composites. The mechanical and dynamic mechanical analysis (DMA) properties of the composites were investigated. The results showed that the addition of POE can increase the impact strength of the composites, and the composites produced via two-stage extruding route showed superior mechanical properties. The results of the DMA confirmed the mechanical tests.

Keywords: Wood Powder; Polyethylene Octene Elastomer (POE); Polypropylene; Impact strength; Dynamic Mechanical Analysis (DMA)

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Introduction

Wood-Plastic Composite (WPC), due to its high stiffness, low density, low cost, environment friendly characteristics such as recyclablity and biodegradability, is gaining more and more interests, both in research and application. However, one obstacle that restricts the application of this hybrid material is owing to the remarkably decreased impact strength (Cantero *et al.* 2003; Lundquist *et al.* 2003).

The toughness of filled polymers can be improved in several ways: 1) increase the matrix toughness; 2) optimize the interface (or interphase) between the filler and the matrix through the use of coupling agents, comptibilizer, and sizes; 3) optimize the filler-related properties such as filler content, particle size, and dispersion; 4) aspect ratio and orientation distributions also play a role in toughness of composites containing more fibrous materials (Utracki *et al.* 1992).

Recently, the Polyethylene Octene Elastomer (POE) has been broadly used in the plastic industry, and the application of POE can significantly increase the impact strength of the filled polymers (Bartczak *et al.* 1999; Zhang. *et al.* 2002; Lim. *et al.* 2006; Wahit. *et al.* 2005). Since in the system of WPC, the plastic used serves as the matrix, which endows the composites mechanical strength, based on the theory of Utracki, increasing the toughness of the matrix can simultaneously improve that of the WPC. The present study is to investigate how the mechanical properties of WPC will change by incorporating POE and adopting two different extruding routes, i.e. direct extruding and two-stage extruding.

Materials and methods

Materials

The materials used in this study were Polypropylene (PP), Polyethylene Octene Elastomer (POE) and Wood Powder. PP (powder) was K1003 (Yanshan Chemical Corp., Beijing), with the melt flow index of 1.2g·10 min^{-1} at 190 ºC. POE was Dupont 8999, which was purchased in the market. The wood powder was made and screened by mill machine and meshes at the laboratory, with the size of below 150μm.

Additives used included an antioxidant (1010), processing stabilizer (DLTP), and Aluminic Acid ester.

Surface treatment of wood powder

Aluminic Acid ester was used as coupling agent for the surface modification of wood powder. Wood Powder was placed in a high-speed blender and heated to 110 ºC with continuously stirring at 5000 r·min^{-1} for 10 min, then Aluminic Acid ester was added, and the whole treatment finished after 5 min. The treated wood powder was prreserved for later use. (Qin *et al.* 2005)

Composites preparation

In the composite, the content of wood powder is 60 wt.%, and the amount of POE is in a proportion of 15 wt.% and 30 wt.% of PP. The composites were extruded following two ways:

(1) Direct extruding: Wood powder, PP, POE and additives were added simultaneously into high-speed blender and then the blend was extruded and palletized on the twin-screw extruder. The pellets were dried in an air drier for 8 h at 80 ºC before being injection-molded into standard test specimens at 180 ºC.

(2) Two-stage extruding: PP, POE and additives were first added into high-speed blender and stirred and then the blend was extruded and palletized on the twin-screw extruder. The second step is compounding the PP/POE pellets with wood powder, and then extruded and palletized. The pellets were then dried in an air drier for 8 h at 80 ºC before being injection-molded into standard test specimens at 180 ºC.

Mechanical test

All tests were conducted at normal temperature conditions according to GB/T standards. Izod impact test (both notched and unnotched) was performed according to GB/T1843. Flexural and tensile properties were evaluated according to GB/T9341 and 1040, respectively. At least five specimens were tested for each sample and property.

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Dynamic mechanical test

The dynamic mechanical properties of the composites were measured with TA-DMA 2980 Dynamic Mechanical Analyzer by using single cantilever bending method in the temperature range of -100 ºC to 160 ºC. The specimens were injection-molded on an inject machine with the dimension of 35mm×13mm×2mm, and were tested in a nitrogen atmosphere in a fixed frequency of 1 Hz and a heating rate of 3 ºC $\cdot min^{-1}$.

Results and discussion

Mechanical properties

Table 1 shows the mechanical properties of the POE-modified Wood-Polypropylene Composites. The composites were prepared following two different routes, direct extruding and two-stage extruding. As can be observed in Table 1, the three figures that represent the toughness of WPC, i.e, the Notched Izod Impact Energy, the Unnotched Izod Impact Energy and the Elongation at Break, all increased remarkably as the increase of POE amount, regardless of which extruding method was adopted. For Notched Izod Impact Energy, the addition of 30% POE and adoption of two-stage extruding gained a significant increase of more than 61%, from $3.22 KJ\cdot m^{-2}$ to $5.19 KJ\cdot m^{-2}$, almost comparable to the pure PP, for which the Notched Izod Impact Energy is $7.38 KJ\cdot m^{-2}$. This means that the presence of POE in WPC system can act to prevent the propagation of the crack. For Unnotched Izod Impact Energy and the Elongation at Break, compared to pure PP, the addition of wood flour causes such a sharp decrease that incorporation of POE can not sufficiently make up the gap; however, POE modified WPC also showed superior unnotched toughness. It is also shown that at the same level of POE content, the composites produced via two-stage extruding route manifest superior impact strength than those prepared via direct extruding route. The lower properties caused by direct extruding method may be due to the poor interfacial interaction among wood powder, PP and POE. While adopting two-stage method, in which the PP and POE were extruded in advance of adding wood powder, PP and POE can merge harmoniously to produce a uniform matrix, so the composites derived from this matrix exhibit higher toughness. Although incorporating POE in the composites can enhance the toughness, the stiffness is also reduced, as seen from Table 1. It can be observed that the Tensile Strength, the Flexural Strength and the Flexural Modulus which represent the stiffness of the materials all show a certain extent of decrease as the addition of POE. However, the decreased figures can also satisfy the requirement of the Industry Standard. According to Forestry Industry Standard published by the State Forestry Administration of P. R. China, LY/T 1613-2004, Extruded Wood-Plastic Composites, the required minimum levels of Flexural Strength and Flexural Modulus are 20 MPa and 1.8 GPa, respectively. For WPC modified with 30% POE by direct extruding, the Flexural Strength is lower than the standard; however, when adopting appropriate extruding method, i.e, two-stage extruding, the figure can be enhanced and higher than the standard level. It is also observed that two-stage extruding can result in a superior strength than direct extruding. The reason for this higher strength may also be due to the better interfacial interaction caused by extruding PP and POE previously.

Table 1. Mechanical properties of PP and wood-polypropylene composites with different POE content.

	PP	60% wood powder+40%PP	60% wood powder+40%PP (with 15%POE in proportion of PP)		60% wood powder+40%PP (with 30%POE in proportion of PP)	
			Direct extruding	Two-stage extruding	Direct extruding	Two-stage extruding
Tensile Strength(MPa)	32.67	18.18	16.91	16.84	13.87	14.15
Elongation at Break(%)	139.15	1.77	2.04	2.27	2.82	2.97
Flexural Strength(MPa)	28.79	27.88	24.56	24.62	19.33	20.72
Flexural Modulus(GPa)	1.2	3.2	2.8	2.7	2	2.3
Notched Izod Impact Energy(KJ/m^2)	7.38	3.22	3.69	3.84	4.41	5.19
Unnotched Izod Impact Energy(KJ/m^2)	120.46	5.97	6.98	7.42	7.44	8.76

Dynamic mechanical properties

Dynamic mechanical analysis (DMA) can provide reliable information over the relaxation behavior of the composites examined. In order to evaluate the effect of POE on the Wood-Polypropylene Composites, the thermo-mechanical properties of the composites were measured by means of Dynamic mechanical analysis. The storage modulus (E’) of PP and Wood-Polypropylene Composites with and without POE versus temperature is depicted in Fig. 1. It is evident that, compared to pure PP, the presence of Wood Powder can greatly enhance the stiffness of the composites, which is identical with the mechanical properties of corresponding composites showed in table 1. The addition of POE can result in the decrease of storage modulus; however, the stiffness of the composite is still higher than that of pure PP.

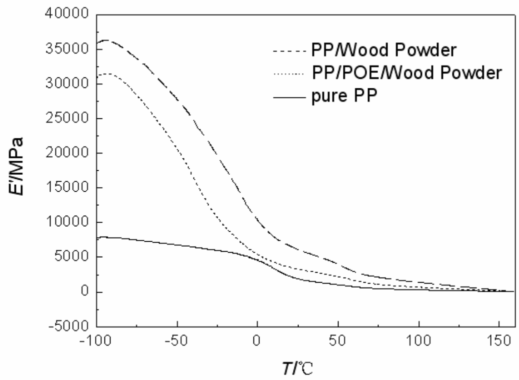

Fig.1 Storage modulus of pure PP and Wood-polypropylene Composites with and without POE

The loss factor (tanδ), as a function of temperature of PP and

Wood-Polypropylene Composites with and without POE, is presented in Fig. 2. For pure PP, two transition temperature were observed in this figure; one at 16ºC corresponding to the β-transition and the other at 80℃ corresponding to α-transition. The curves of wood powder/polypropylene composites with and without POE also show two transitions. The lower peak of pure PP than that of WPC may be due to the higher degree of crystallinity of PP. As can be observed, compared to unmodified Wood-Polypropylene Composites, theβ-transition of POE modified composites shifts to lower temperature, which means a better low-temperature toughness of the composites toughened by POE.

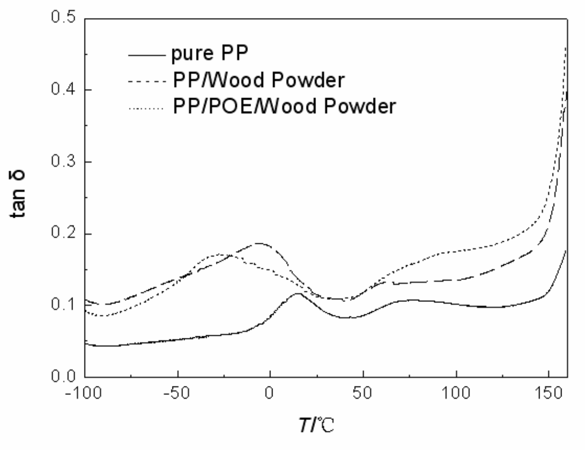

Fig.2 Loss factor(tanδ) of pure PP and Wood-polypropylene Composites with and without POE

Conclusions

This work attempts to enhance the impact strength of Wood-Polypropylene composite via incorporation of POE, and investigate the effect of extruding routes on the mechanical properties of the final products. The main conclusion of this work can be summarized as followed, adding POE in the composites system can greatly enhance the toughness of the composites; however, the stiffness of the composites showed decrease as the addition of POE. At the same level of POE content, the composites manufactured by two-stage extruding method demonstrated superior toughness than those made by direct extruding. When the POE content reached to 30%, compared to direct extruding, two-stage extruding can peoduce composite with better stiffness.

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